Fermilab's Engagement in DUNE Prototyping and Testbeds

Steve Brice

PAC Meeting

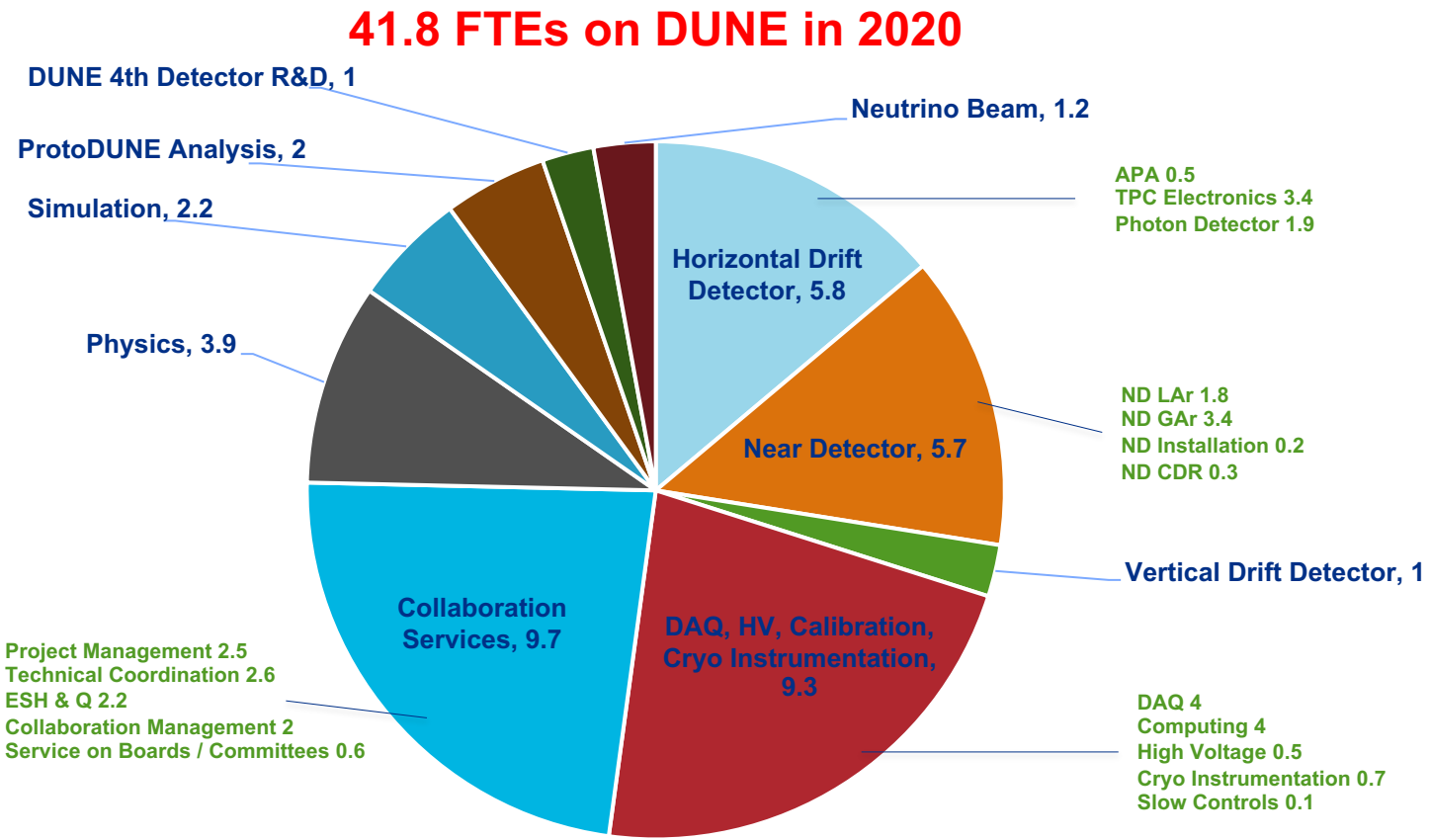
Wed 9 June 2021

Outline

- Fermilab's engagement with DUNE Collaboration – the big picture
- Fermilab's Role
- Prototypes and Testbeds
  - ND-LAr 2x2 Demonstrator
  - PixLAr
  - ProtoDUNE-SP
  - ProtoDUNE II (HD)
  - APA Cold Testing
  - ICEBERG and PAB teststands
  - VD Photon detection
- Summary

DUNE Personnel @ Fermilab in 2020

- Fermilab has 154 DUNE collaborators contributing 41.8 FTEs to DUNE
- In this talk I will talk about only a fraction of this effort – that which is devoted to prototyping and testbeds



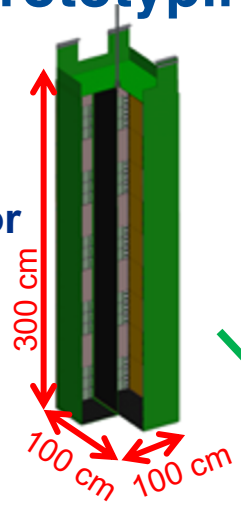
Principles Governing how Fermilab Deploys Resources on DUNE

- Resources are deployed where they can have most impact. Fermilab involvement should be a game changer
- Leverage other Fermilab capabilities (e.g. computing, beam, LAr labs, ….)
- Focus on a handful of areas with strong groups in each
- Fermilab (and the other Natl. Labs) should complement the universities and not compete with them. It's not helpful to the enterprise for Fermilab to behave (or be treated) as if it were a big university

DUNE ND-LAr: From Prototyping to Production to Installation

2019-2021
Module 0

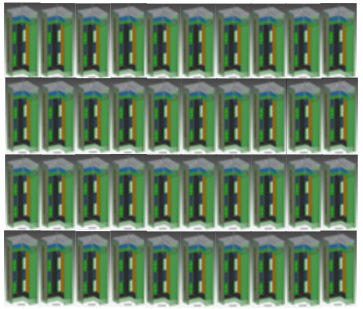
2022-2023
Full-scale Demonstrator



2022-2023
2x2 Demonstrator

2024-2026
Production and testing

35(+5) Production modules
Each tested in single-module cryostat



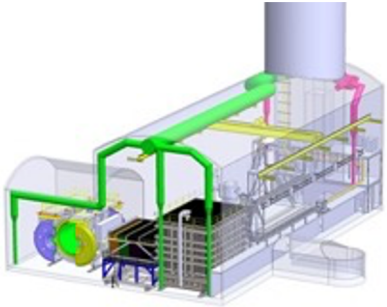
Deliverable: modules packed and ready for installation underground

Test at MATF @ FNAL

2027-2029
Installation

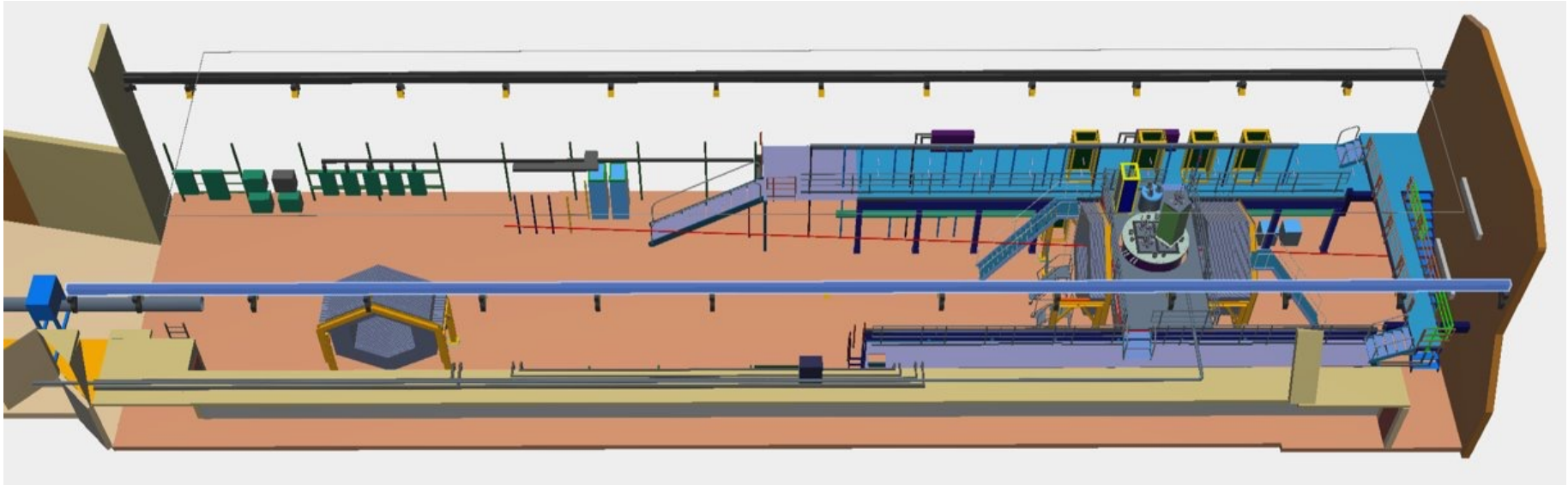
Support of TPC module installation in Near Site

Activity driven by Near Site Integration (NSI)



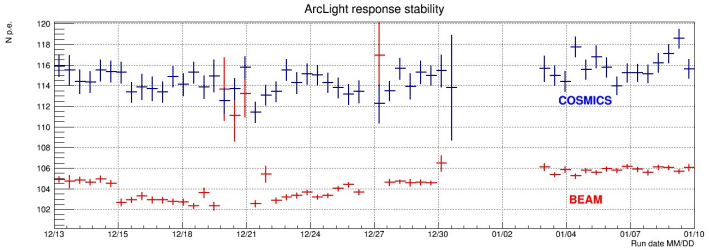
2x2 Installation in MINOS Underground Area

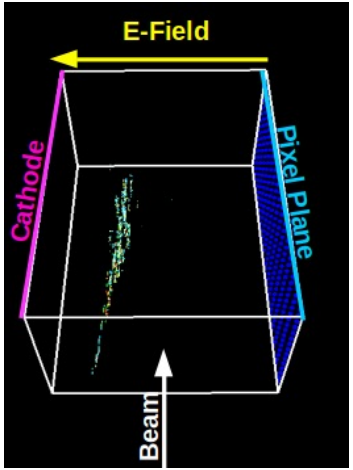
- 2x2 to be installed in the current MINOS near detector location
- Removal of the MINERvA detector is complete
  - Some modules to be reused as a tracker for the 2x2
- Removal of the MINOS near detector expected to finish in mid June

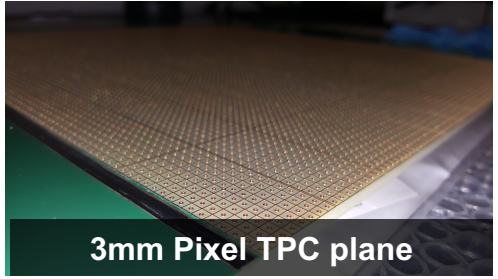


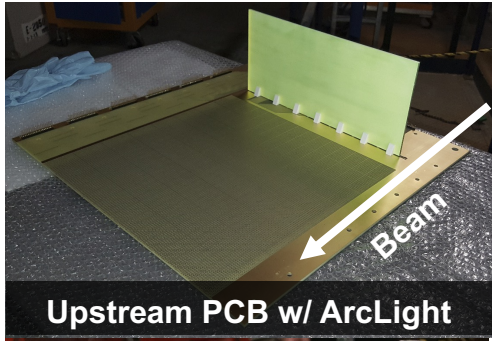
PixLAr (Pixel Liquid Argon Experiment)

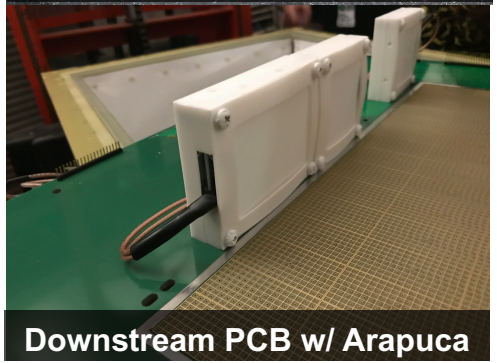
- **PixLAr was one of the early R&D tests of a large scale pixel based LArTPC (FNAL testbeam data taking in 2017)**
  - Existed before dedicated LArTPC ASICs had been developed
- **Used a custom analog multiplexed PCB board with an active pixel area of 36 cm^2 and existing LARASIC readout electronics**
  - 14,400 pixels per PCB board
  - 120 Regions of Interest (ROI's)
  - Total pixel count is 28,800 pixels read out with 480 channels
- **Light detection devices resided on the upstream and downstream areas**
  - ArcLight with 6 SiPM's
  - 3 Aracupa prototypes (each with one SiPM)
- **Demonstrated successful operation of large scale pixel PCB with integrated light detection devices as well as real time 3D event reconstruction**











ProtoDUNE-SP
Mission & accomplishments

- ✓ Prototyping production and installation procedures for DUNE Far Detector Design

  TDR PUBLISHED https://arxiv.org/abs/2002.03010

- ✓ Validating design from perspective of basic detector performance → inform TDR

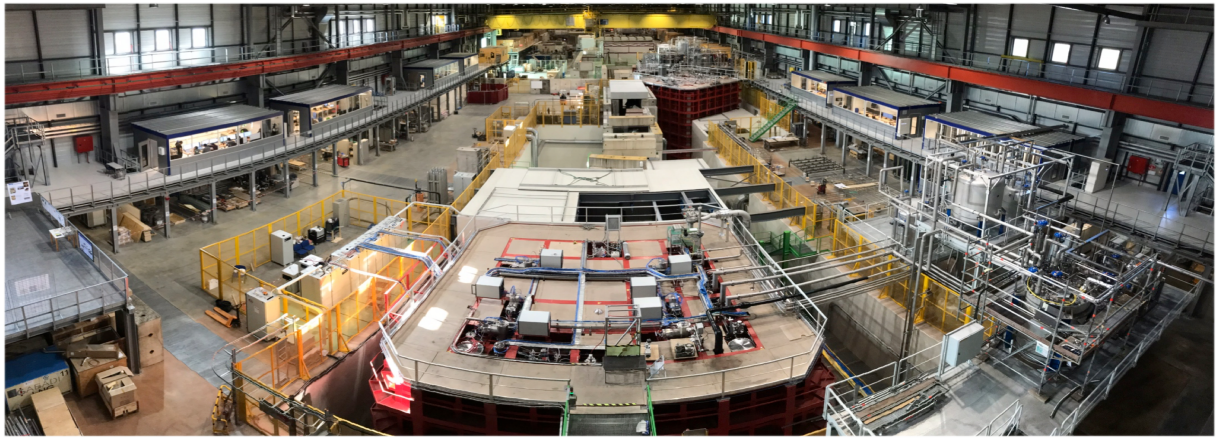
- ✓ Accumulating test-beam data to understand/calibrate response of detector to different particle species

  ~ 4M BEAM TRIGGERS ACCUMULATED AND ANALYZED

  DET. PERFORMANCE - 1ST PAPER PUBLISHED https://arxiv.org/abs/2007.06722

- ✓ Demonstrating long term operational stability

  600+ DAYS OF OPERATION (COSMIC TRIGGERS)



Roles of FNAL People

- E. James - DUNE Tech. Coordinator and J. Mercier (protoDUNE management)
- R. Rameika - protoDUNE Coordinator (detector construction)
- F. Cavanna - protoDUNE Coordinator (detector assembly, activation, operation and performance at CERN)
- R. Acciarri - protoDUNE on-site Technical Leader (detector integration, installation and test at CERN, and Run Coordinator)
- T. Yang (protoDUNE Data Reconstruction and Analysis Leader)
- G. Savage (on-site Computing infrastructure coordinator)
- S. Pordes (Cryo-Instrumentation coordinator)
- L. Bagby, T. Shaw (Grounding & Shielding coordinator)
- R. Pordes (FNAL-CERN Computing Liaison)
- A. Norman (DUNE SW and Computing coordinator)

On-site expert/sub-system leader

- S. Lockwitz (HV System)
- B Ramson (Photon Detectors)
- J. Paley (Beam Instrumentation)
- D. Montanari (Cryogenics System)
- A. Hanh (Cryo-Instrumentation)
- B. Baller (Data Quality Monitor)
- K. Biery (artDAQ)
- W. Ketchum (run Ctrl)

Neutrino Platform

Coordinator:
Marzio Nessi (CERN)

EHN1 Coordinator:
Filippo Resnati (CERN)

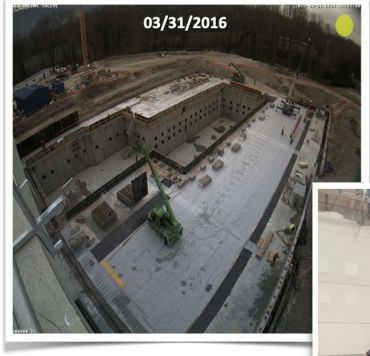
DUNE ProtoDUNE SP

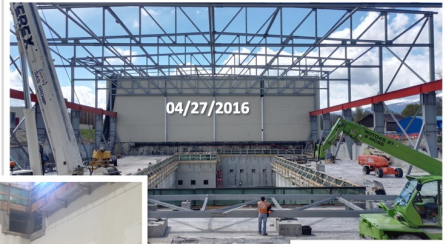
Coordinators:
Flavio Cavanna (FNAL)
Christos Touramanis (Liverpool)
Regina Rameika (FNAL-Construction)

Engineering Intergration: Jack Fowler (Duke)
Computing Liason: Ruth Pordes (FNAL)

Realization of the Neutrino Platform at CERN

in few snapshots: Mar. 2015 - Oct. 2016





EHN1 extension

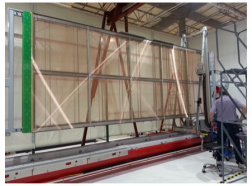
beneficial occupancy
September 2016

Modular approach

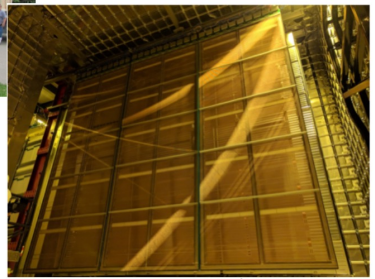
Realization of protoDUNE Detector Components

e.g. the APA Journey –
build (in US and UK), ship to CERN, prep & test (Neutrino Platform), install in protoDUNE

March 2017



July 2017



February 2018

September 2017

October 2017

March 2018 IPR Review :
3 APAs in cryostat

ProtoDUNE-SP Detector Integration, Test and Installation at CERN

Detector Integration,
Testing, and Installation

Coordinator: Roberto Acciarri (FNAL)

Installation Team Leader:
Bill Miller (Minnesota)
Integration/Test Coordinator:
Andrea Zani (CERN)
Electrical/Cabling Coordinator:
Flor Blaszczyk (BU) (now at FNAL)
Computing Infrastructure Coordinator:
Geoff Savage (FNAL)
Grounding & Shielding Coordinator:
Linda Bagby (FNAL)
Safety Coordinator:
Olga Beltramello (CERN)

APA Commissioning Leaders:
Andrzej Szelc (Manchester)
Serhan Tufanli (Yale)

HV/CPA/FC Commissioning Leaders:
Francesco Pietropaolo (CERN)
Kevin Wood (SBU)

Beam Plug Commissioning Leader:
Cheng-Ju Lin (LBNL)

Photon Detector Commissioning Leader:
Ettore Segreto (Campinas)

Photon Electronics Commissioning Leader:
Zelimir Djurcic (ANL)

Cold Electronics Commissioning Leaders:
Carl Bromberg (MSU)
Matt Worcester (BNL)

Muon Tagging Detector
Commissioning Leaders:
Steve Manly (Rochester)
Camillo Mariani (Virginia Tech)

Detector assembly, test and installation

- Detector components delivery at CERN
- Detector Integration (Clean Room):
  - *APA + CE + PD (#1→ #6)*
- DAQ Vert Slice
- Test in Cold Box at ~LAr T
  - » Move into Cryostat through TCO
  - » Installation/Assembly in Cryostat:
    - *(APA+CE+PD) + CPA + FC*
- Cabling

and also:

- Local Computing infrastructure
- Grounding
- Safety

DAQ

Coordinators:
Karol Hennessy (Liverpool)
Giovanna Lehmann Miotto (CERN)

Run Control/Systems Monitor Leader:
Wesley Ketchum (FNAL)

Data Monitoring Leader:
Antonino Sergi (Birmingham)

artDAQ Leader:
Kurt Biery (FNAL)

Photon Detector Readout Leader:
Martin Haigh (Warwick)

RCE TPC Readout Leader:
Mathew Graham (SLAC)

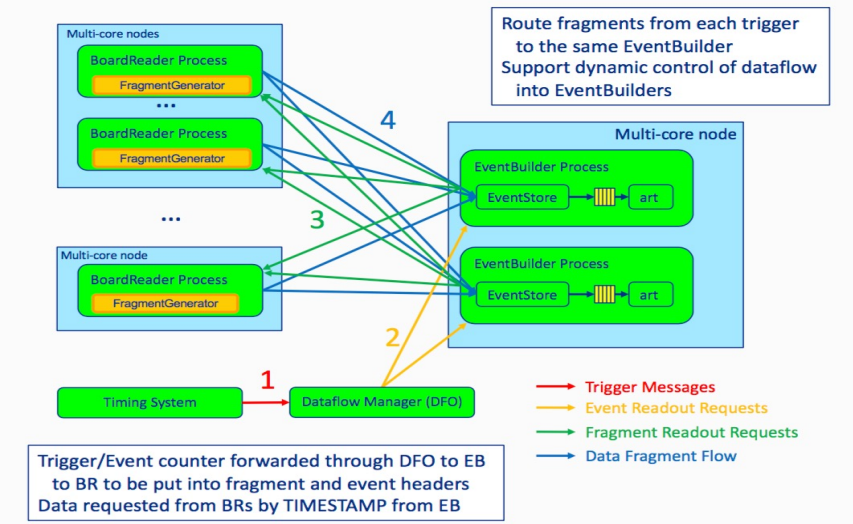
FELIX TPC Readout Leader:
Frank Filthaut (NIKHEF)

Trigger System Leader:
Josh Klein (Penn)

Timing System Leader:
David Newbold (Bristol)

ProtoDUNE-SP DAQ System

Parameter	Value
Trigger rate	25 Hz
Spill duration	4.8 s
SPS Cycle	22.5 s
Readout time window	5 ms
# of APAs to be read out	6
Single readout size (per trigger)	230.4 MB
Lossless compression factor	4
Instantaneous data rate (in-spill)	1440 MB s^{-1}
Average data rate	576 MB s^{-1}
3-Day buffer depth	300 TB



Cryogenics & Argon Instrumentation

Coordinators:
Stephen Pordes (FNAL)
Anselmo Cerbera (Valencia)

Internal Cryogenics & Cryomeasurements leader:
Alan Hahn (FNAL)

Cryogenics Operation PTL Monitor Leader:
Xavier Ponas (CERN)

LAr Vertical Temperature Monitor Leader:
Jelena Maricic (Hawaii)

LAr Purity Monitor Leaders:
Jiaming Bian (UC-Irvine)
Andrew Renshaw (Houston)

GAr Purity Analyzer Leader:
Stephen Pordes (FNAL)

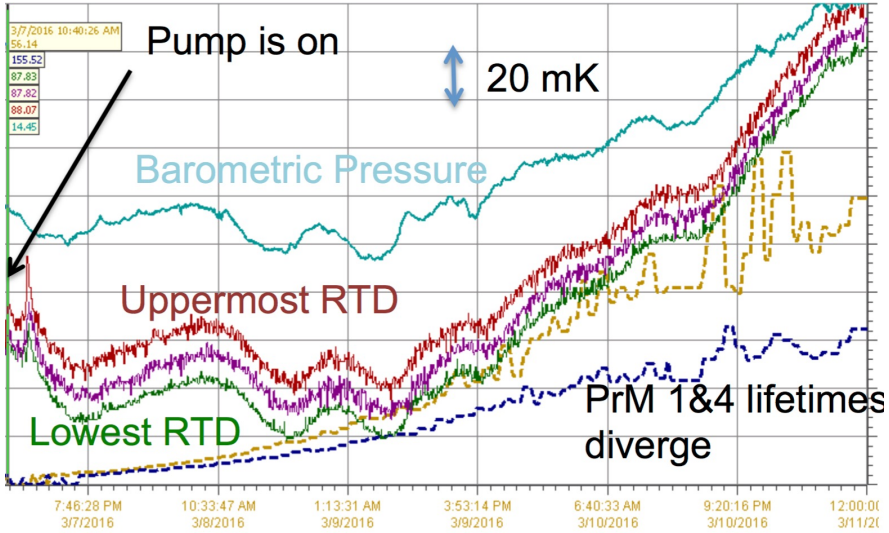
Cryostat Internal Cameras Leader:
Mike Kordosky (William & Mary)

Instrumentation Readout Leader:
Flor Blacszcyk (Boston)

ProtoDUNE-SP Cryogenics and Argon Instrumentation

Pressure, Temperature,Purity
on the same plot

(example from the 35t run)



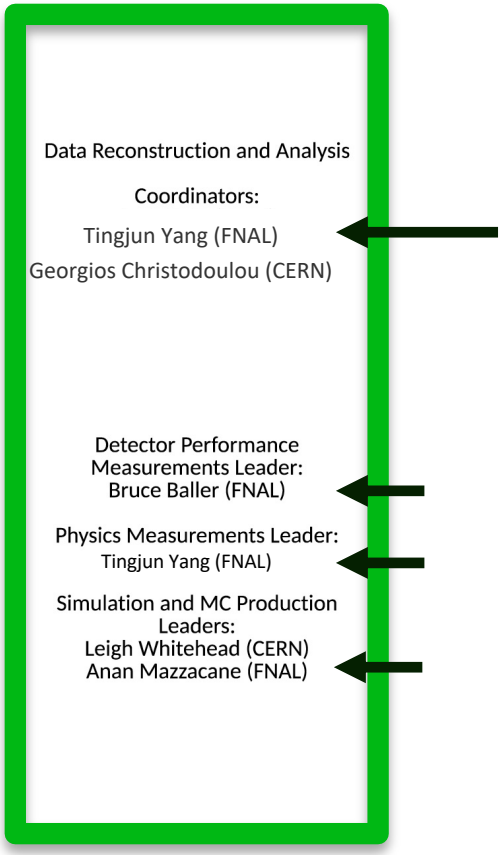
ProtoDUNE-SP Data Reconstruction, Calibration and Analysis

(1) Detector Performance Measurements:

- First demonstrate that the performance of the ProtoDUNE detector is sufficient to make physics measurements (input to DUNE TDR)
  - Signal to Noise Ratio (SNR)
  - LAr Purity and range-based PID
  - Space charge
  - Calorimetric Reconstruction

(2) Physics Measurements:

- Few selected physics topics for an expedite analysis output *(goal: public presentation in ~6 months after run end)*
  - pion cross-section in the 1 to 7 GeV range
  - el.m shower content in hadron shower (compensation in LAr)



Jinst

Published by IOP Publishing for Sissa Medialab

Received: *July 30, 2020*
Accepted: *October 18, 2020*
Published: *December 3, 2020*

First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform

DUNE

The DUNE collaboration

E-mail: cavanna@fnal.gov, trj@fnal.gov, tjyang@fnal.gov

Abstract: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber with an active volume of $7.2 \times 6.1 \times 7.0$ m^3. It is installed at the CERN Neutrino Platform in a specially-constructed beam that delivers charged pions, kaons, protons, muons and electrons with momenta in the range 0.3 GeV/c to 7 GeV/c. Beam line instrumentation provides accurate momentum measurements and particle identification. The ProtoDUNE-SP detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment, and it incorporates full-size components as designed for that module. This paper describes the beam line, the time projection chamber, the photon detectors, the cosmic-ray tagger, the signal processing and particle reconstruction. It presents the first results on ProtoDUNE-SP's performance, including noise and gain measurements, dE/dx calibration for muons, protons, pions and electrons, drift electron lifetime measurements, and photon detector noise, signal sensitivity and time resolution measurements. The measured values meet or exceed the specifications for the DUNE far detector, in several cases by large margins. ProtoDUNE-SP's successful operation starting in 2018 and its production of large samples of high-quality data demonstrate the effectiveness of the single-phase far detector design.

1066 Total downloads

6 48

Turn on MathJax

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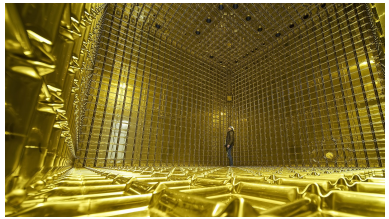


News article

Role of FNAL People

Data Processing & MC production
K. Herner

Corresponding Authors:
F. Cavanna (FNAL)
T. Junk (FNAL)
T. Yang (FNAL)

Main Contributions:
T. Yang (Calibration - Sec.4, Sec.6))
W. Wu (Evt. Reconstruction - Sec.4)
D. Totani (PhDet- Sec.5, Sec.7)
B. Ramson (PhDet - Sec.5)

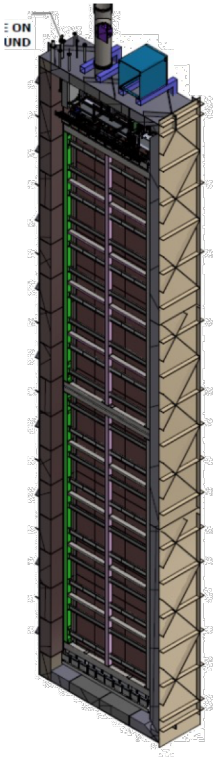
ProtoDUNE-II (HD)

- Installation through CY22 with start of beam operations scheduled for end CY22

- The consortia are much more established than they were at this stage of ProtoDUNE-SP
  - They can relied upon for their deliverables
  - Fermilab people play key roles in several consortia

- Fermilab intends to send a strong team to help with ProtoDUNE-II just like we did for ProtoDUNE-SP
  - It's not yet clear whether the senior leadership team that Fermilab provided for ProtoDUNE-SP will be requested for ProtoDUNE-II (HD). The lab will supply what is needed.
  - Eric James has particularly requested long term stays by Fermilab postdocs

Testing and storage of APAs at Fermilab



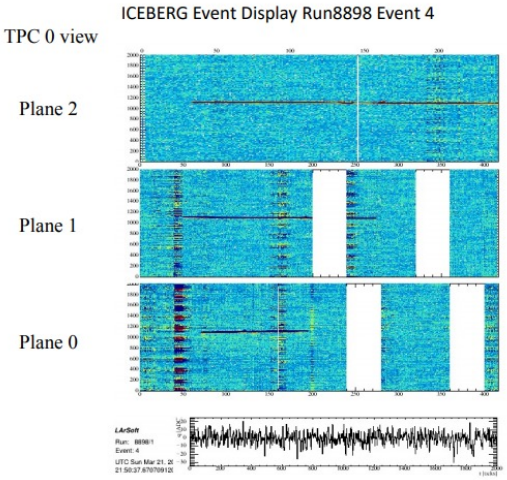
- APA production in UK for FD1-HD starting late 2021
- Warehouse in SD not yet available, no crew there yet with appropriate training to handle APAs
- Necessary to find storage place at Fermilab, managed by well-trained technicians
- D0 Assembly Building (DAB) and Wideband Photon Lab are realistic possibilities for storage
- It is essential to monitor APA quality over the ~5 years production
- Pit area at DAB suitable to cold test ~10% of APA production
- It offers the opportunity to assemble and test a full size cold box (~14 m high) with cryogenic system, later to be moved to SURF for installation
- Some nice DAB features: “orange structure” can be converted to APA-doublet assembly tower; top of cold box accessible from the top of concrete blocks wall

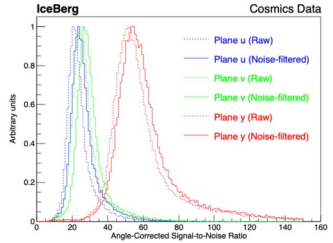
ICEBERG

- Large cryostat (left, 152 cm diameter), 35k liters of LAr
- Houses 115 cm x 100 cm x 60 cm TPC (center, 1280 wires, 10 FEMBs), suspended from top plate (right picture)
- Meant for testing different types of front-end electronics for the APA readout with quick turnaround (1.5 months)

ICEBERG

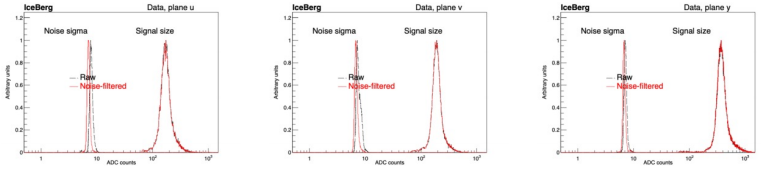
- Three commissioning runs with ProtoDUNE FEMBs, followed by data taking periods with SBND FEMBs and first DUNE prototype FEMBs with 3 ASIC solution, direct comparison of performance in identical data taking conditions





Plane	Most probable value	
	Raw data	Noise-filtered
Induction U	21.4 ± 0.1	23.9 ± 0.1
Induction V	24.8 ± 0.1	27.3 ± 0.1
Collection Y	51.9 ± 0.1	54.7 ± 0.1

Plane	Average	
	Raw data	Noise-filtered
Induction U	24.3 ± 0.1	27.1 ± 0.1
Induction V	27.6 ± 0.0	30.6 ± 0.1
Collection Y	59.6 ± 0.1	62.4 ± 0.1



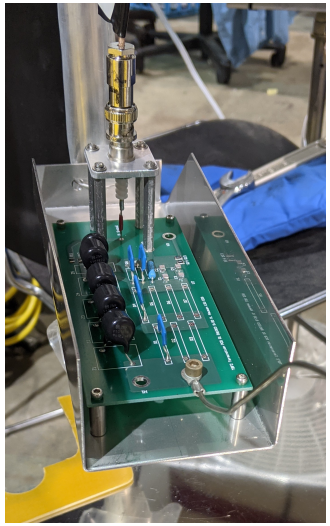
- Planning further tests with CRYO FEMBs for June/July, final FEMB prototypes with final version of ASICs for DUNE in the Fall

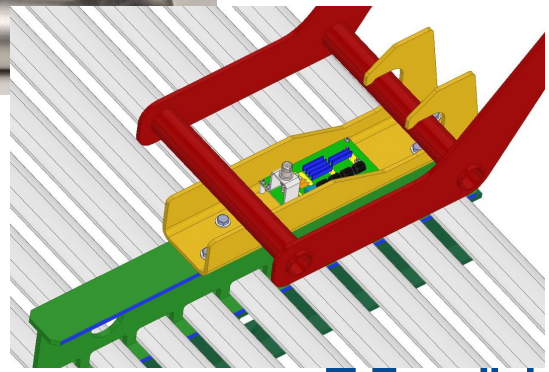
ICEBERG

- The setup is very flexible, originally designed to test / compare different versions of front-end electronics for APAs
- Currently testing high voltage extender meant for installation in ProtoDUNE-DP (later vertical drift TPC)
- Key is fast turnaround (1.5 months), low cost ($6k of LAr per fill)
- Almost completed test plan for TPC electronics readout, will still use ICEBERG for:
  - Study of possible interference between different detectors (TPC electronics, photon detector, cryogenic instrumentation) prior to installation of ProtoDUNE-II
  - Test of new services for DUNE detector (new PLC based detector safety system, new warm electronics)
  - Could replace anode plane assembly (wire based) with strip-based detector (vertical drift TPC) or pixel-based detector (PixLAr, Qpix)
  - Further tests of photon detectors, study impact of LAr doping to enhance response to photons
  - Any new ideas

HV Component Testing

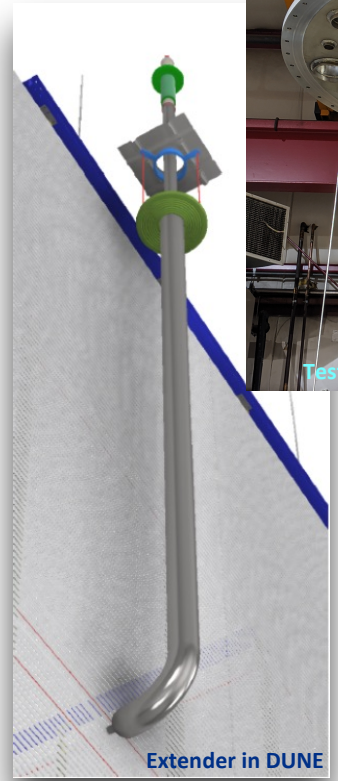
- Tested ProtoDUNE/DUNE resistive end caps in the Blanche cryostat at the PAB
  - End caps are used to terminate the ends of the field cage profiles
  - The test showed that more HV activity was associated with resistive end cap areas
    - Keeping the initial polyethylene design
- Resistive-core cable
  - Tested filtering ability of HV cable.
  - Filtering is needed to remove the ripple from HV PSs. Currently use a resistor inline with the cable to make a lowpass filter
  - A resistive core is attractive since it allows for no breaks in the cable
- DUNE field cage termination board
  - Tested to full voltage in a housing similar to the field cage. Concern was primarily the the solder bumps. Passed!

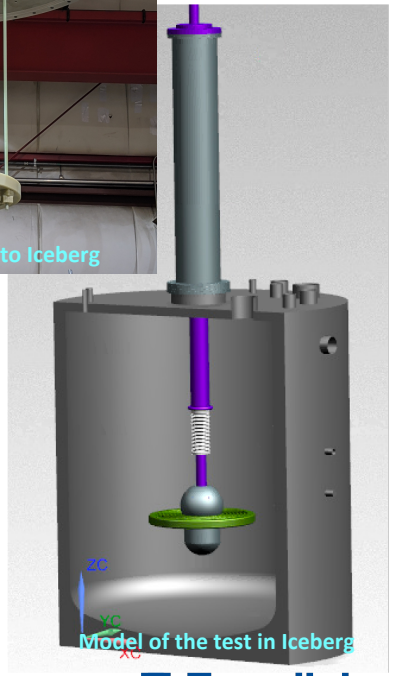




Vertical Drift Extender Test

- A new extender design is planned for the vertical drift prototype
  - Delivers HV from the feedthrough to the cathode ~6 meters away
  - A test of the critical components is taking place in the Iceberg cryostat at the PAB
    - Sphere, G10 interface, welds
  - In parallel, parts for the upper and lower section of the extender are being prepared to ship to CERN next month

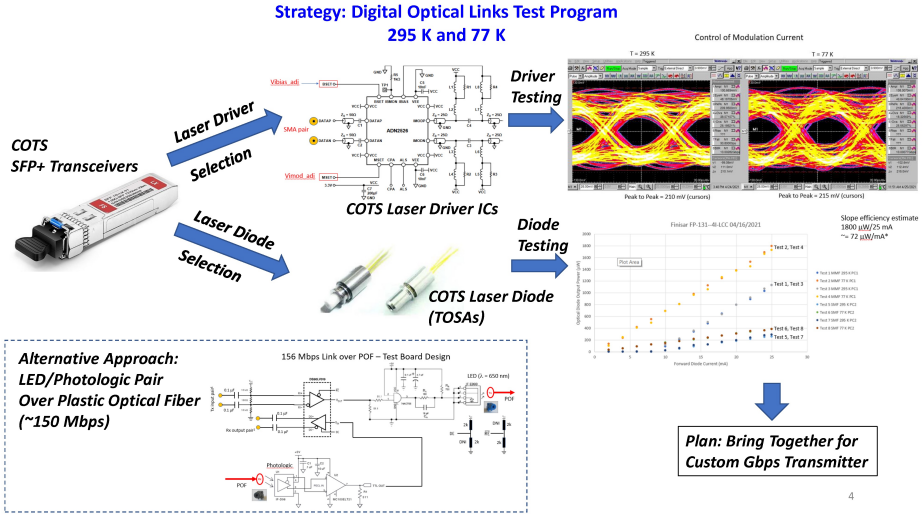




VD Photon Detection

- Strong engagement by Fermilab Scientists
- Very fast timeline for R&D
- PAB being used for cold tests of COTS electronics
  - LN2 and LAr
- Intend for Fermilab to play a large role in the engineering, prototyping and fabrication of final system
  - May site production line at Fermilab if suitable university location not available

Baseline Date	Activities/Milestone
May 2021	T4 Milestone: Pair-wise Short-term Cold Test Validation
June 2021	Launch pre-prototype PCB and CAD designs. Order long lead-time components.
July 2021	T4 Milestone: All-channel Detector + Waveform Transmission prototype validated in short-term cold test.
August 2021	T4 Milestone: Two synchronized tile electronics prototypes short-term validated in cold.
September 2021	T4 Milestone: Ready for CERN Cold Box Test
November 2021	T4 Milestone: CERN Cold Box Tests of two synchronized prototypes complete
January 2023	T4 Milestone: All components validated for 30-years in cold



Summary

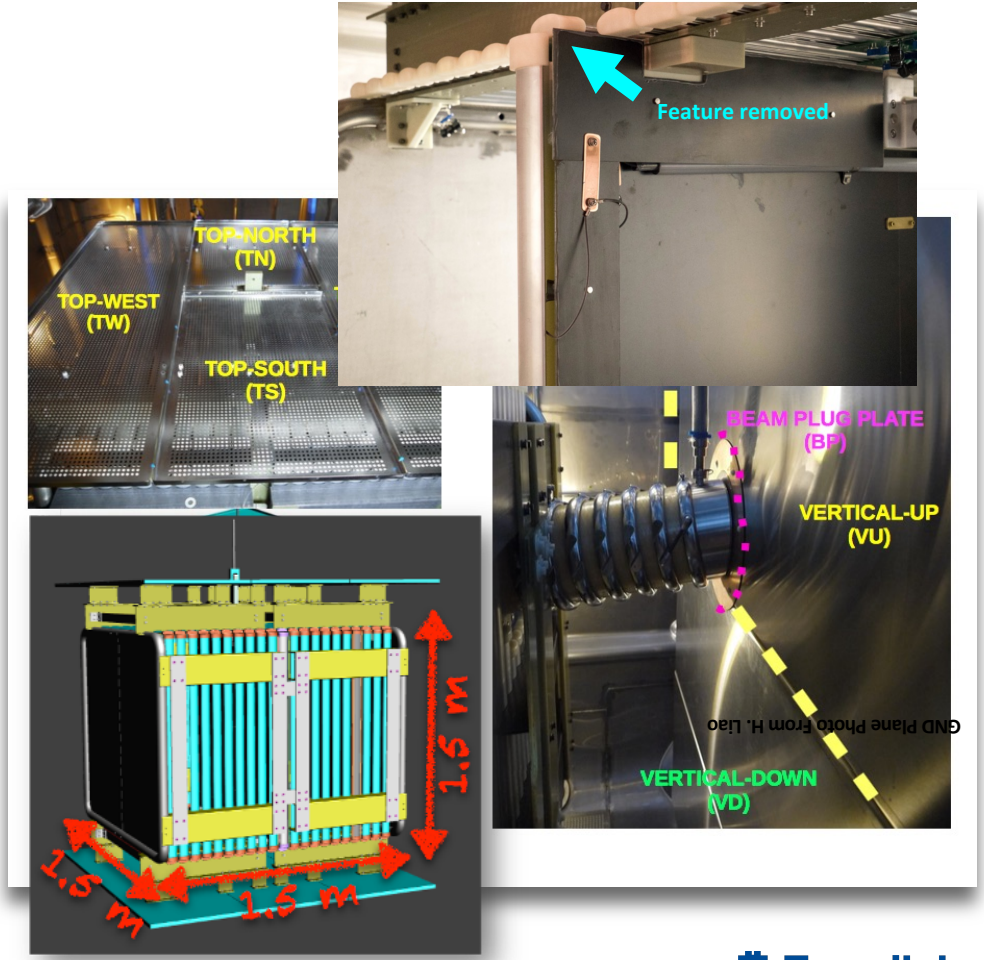
- The lab choses carefully how it devotes resources
  - Resources are deployed where they can have most impact. Fermilab involvement should be a game changer
  - Leverage other Fermilab capabilities (e.g. computing, beam, LAr labs, ….)
  - Focus on a handful of areas with strong groups in each
  - Fermilab (and the other Natl. Labs) should complement the universities and not compete with them. It's not helpful to the enterprise for Fermilab to behave (or be treated) as if it were a big university

- Fermilab is engaged in a number of prototypes and testbeds
  - ND-LAr 2x2 Demonstrator
  - PixLAr
  - ProtoDUNE-SP
  - ProtoDUNE II (HD)
  - APA Cold Testing
  - ICEBERG and PAB teststands
  - VD Photon detection

Extras

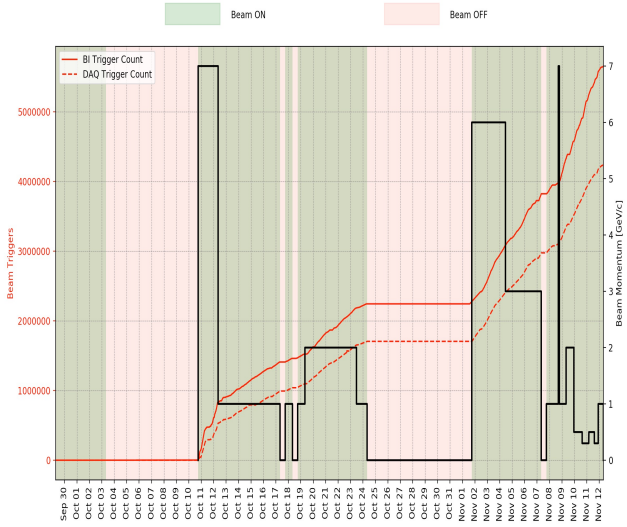
35T ProtoDUNE-SP Tests

- 3 runs from April 2016 - March 2018 (initial field cage (FC) design, FC with beam plug, FC without beam plug)
- Showed a feature in the initial design caused instabilities
  - So-called “streamers” — extended current draws that drop the voltage & make noise
  - Feature has since been removed
- Studied purity dependence on instabilities
  - Saw no dependence on argon flow rate
- Led to development of ground plane instrumentation to help identify sources of HV instabilities
- Showed the beam plug does not hurt HV performance — was installed in ProtoDUNE-SP



ProtoDUNE-SP Beam Data Accumulation

Particle content based on the expected rates from the Geant simulation of the beamline



Momentum (GeV/c)	Total Triggers Recorded (K)	Total Triggers Expected (K)	Expected Pi trig. (K)	Expected Proton Trig. (K)	Expected Electron Trig. (K)	Expected Kaon Trig. (K)
0.3	269	242	0	0	242	0
0.5	340	299	1.5	1.5	296	0
1	1089	1064	382	420	262	0
2	728	639	333	128	173	5
3	568	519	284	107	113	15
6	702	689	394	70	197	28
7	477	472	299	51	98	24
All momenta	4173	3924	1693.5	777.5	1381	72

All Data collected in Beam Positive Polarity Mode

(no Negative Polarity data)

Bonus:
Data taking in the Low Momentum range (below 1 GeV/c)

From the DUNE Beam Time request for 2018 submitted to SPSC on Oct. 11, 2017

- **Physics Run**
  [expected 3000 spill/day]:
  Hadron Beam - Goals:
  ≥ 500 k Pion evt per momentum setting (~3 M Total π-sample)
  ≥ 100 k Proton evt per momentum setting (700 k Total p-sample)

  Electron Beam - Goal:
  ≥ 75 k Electron evt per energy setting (900 k Total e-sample)

Run Coordinators

R. Acciarri (FNAL)

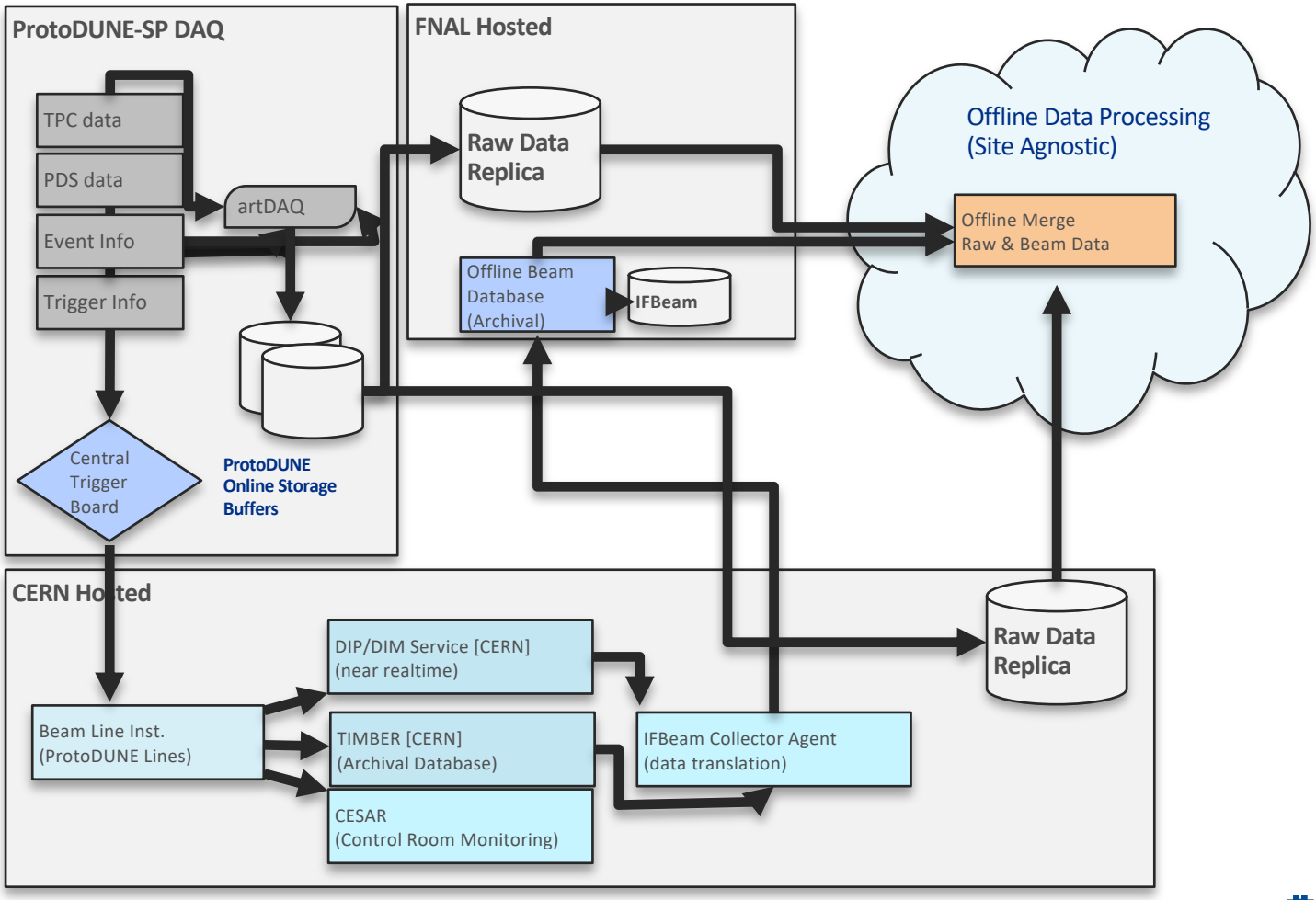
F. Resnati (CERN)

A. Zani (CERN)

+

G. Savage (Computing and DAQ support on-site)

Data Transfer & Storage
Data Processing and Reconstruction

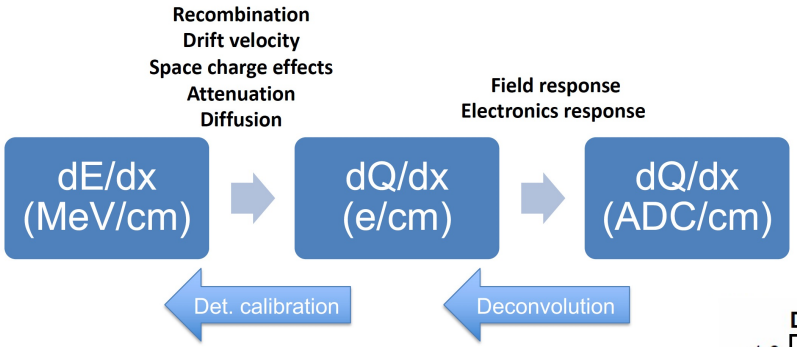


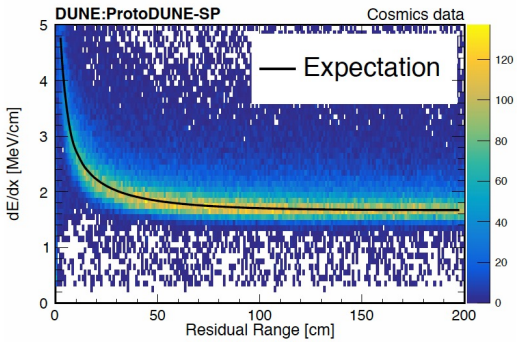
A. Norman
S. Timm

I. Mandrichenko

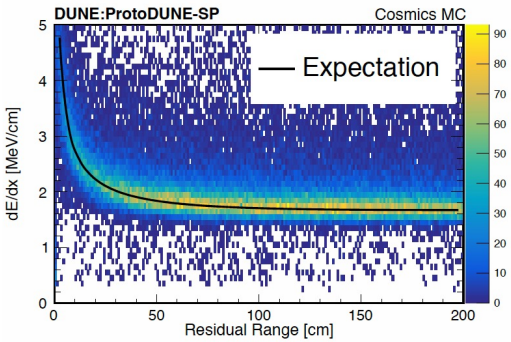
Example of an Integrated System: ProtoDUNE Beam Inst. Readout for Offline -

TPC signal formation and calibration

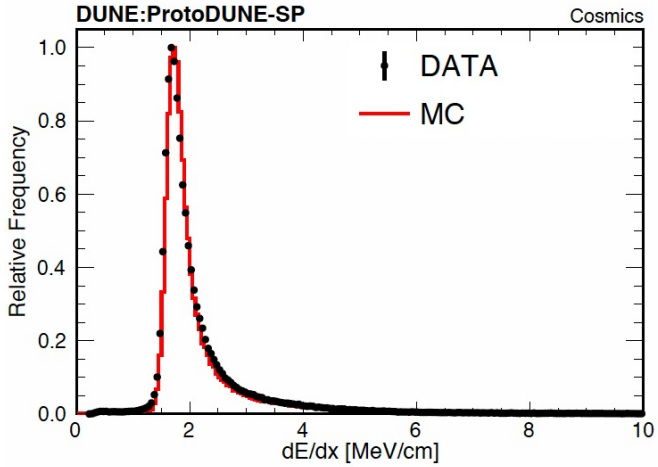




(a) Data

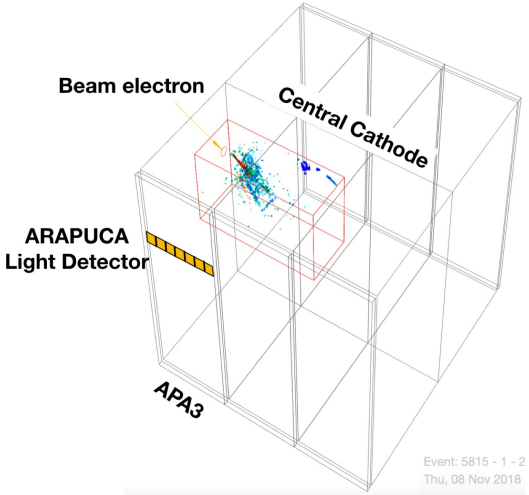


(b) MC

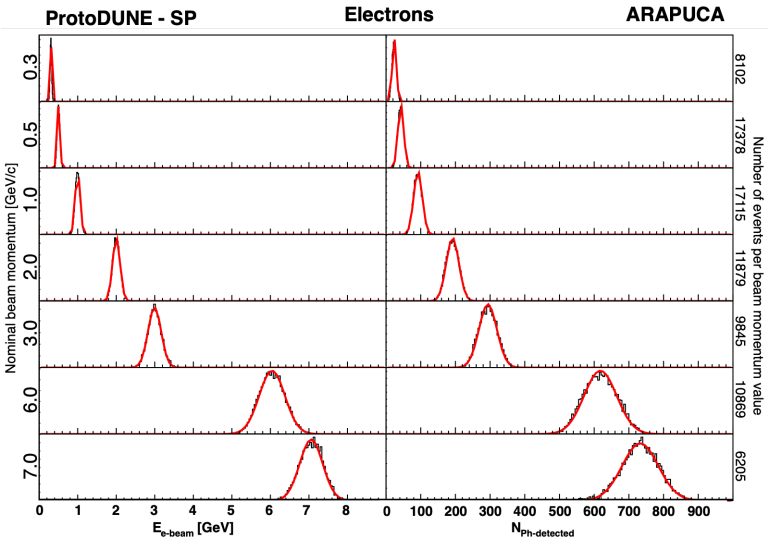


(c) dE/dx comparison

PHOTON DETECTOR PERFORMANCE :



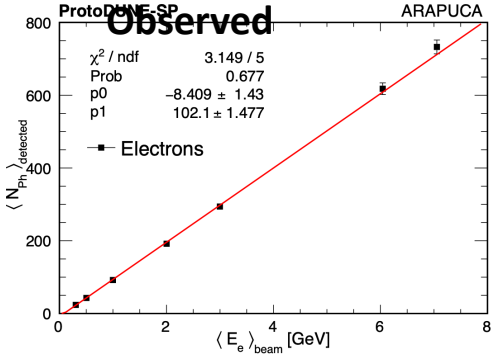
calorimetric response to EM showers from *light signal*

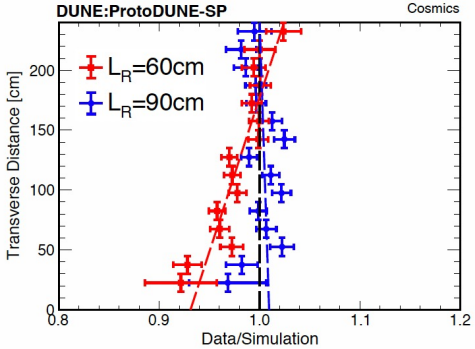


Incident Electron momentum distribution

detected photons spectra

Linearity



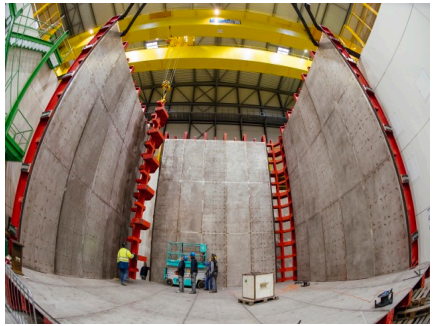


single ARAPUCA module (~0.5‰ photo-sensitive area coverage)

EM shower at ~3 m distance in the x (drift) direction

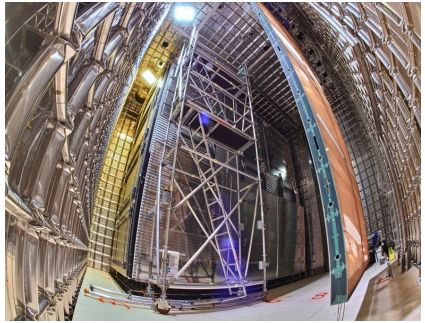
PROTO DUNE SP in few snapshots

March 2016, construction of EHN1 extension

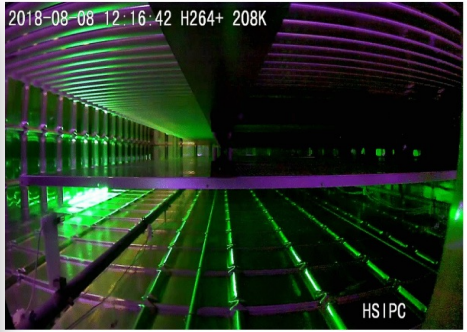


November 2016, cryostat structure assembly

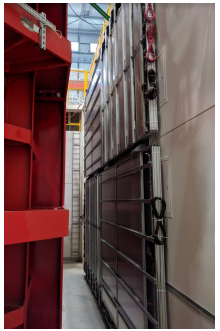
September 2017, cryostat completed



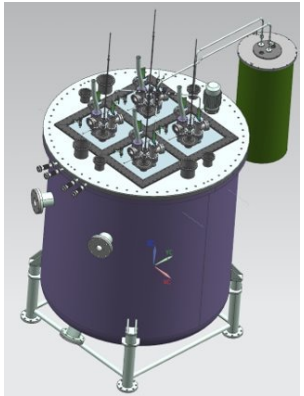
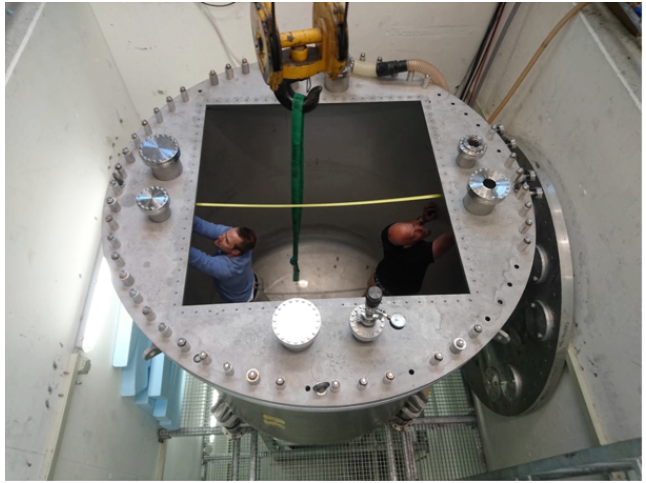
February 2018, detector assembly (ship-in-a-bottle)



August 2018, LAr filling



September 19, 2018 - DAQ and CRT: ready for beam!

2x2 Key Points

- The 2x2 is a vital part of the prototyping plan of the DUNE ND-LAr consortium
  - The only testbed for multiple modules prior to final detector construction
  - Engineering shakedown of a multiple module system with large sample of neutrino events (including full processing chain)
- Most hardware funded by Swiss grant to University of Bern
- Cost and Schedule review to be held in early August
- Expect to run for ~6 months
- Option of being a testbed for other DUNE Near Detector elements (i.e. ProtoDUNE-ND)